Report of the

Astronomy and Astrophysics Advisory Committee

March 8, 2013

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March 8, 2013

Dr. Subra Suresh., Director
National Science Foundation
4201 Wilson Blvd., Suite 1205
Arlington, VA 22230

Mr. Charles F. Bolden, Jr., Administrator
Office of the Administrator
NASA Headquarters
Washington, DC 20546-0001

Dr. Steven Chu, Secretary of Energy
U.S. Department of Energy
1000 Independence Ave., SW
Washington, DC 20585

The Honorable John D. Rockefeller, IV, Chairman
Committee on Commerce, Science and Transportation
United States Senate
Washington, DC 20510

The Honorable Ron Wyden, Chairman
Committee on Energy & Natural Resources
United States Senate
Washington, DC 20510

The Honorable Lamar Smith, Chairman
Committee on Science, Space and Technology
United States House of Representatives
Washington, DC 20515

Dear Dr. Suresh, Mr. Bolden, Secretary Chu, Chairman Rockefeller, Chairman Wyden, and Chairman Smith:

I am pleased to transmit to you the annual report of the Astronomy and Astrophysics Advisory Committee for 2012–2013.

The Astronomy and Astrophysics Advisory Committee was established under the National Science Foundation Authorization Act of 2002 Public Law 107-368 to:

(1) assess, and make recommendations regarding, the coordination of astronomy and astrophysics programs of the Foundation and the National Aeronautics and Space Administration, and the Department of Energy;

(2) assess, and make recommendations regarding, the status of the activities of the Foundation and the National Aeronautics and Space Administration, and the Department of Energy as they relate to the recommendations contained in the National Research Council's 2001 report entitled *Astronomy and Astrophysics in the New Millennium* and the recommendations contained in subsequent National Research Council reports of a similar nature;

(3) not later than March 15 of each year, transmit a report to the Director, the Administrator of the National Aeronautics and Space Administration, the Secretary of Energy, the Committee on Commerce, Science and Transportation of the United States Senate, the Committee on Energy and Natural Resources of the United States Senate, and the Committee on Science, Space, and Technology of the United States House of Representatives, on the Advisory Committee's findings and recommendations under paragraphs (1) and (2).

The attached document is the tenth such report. The executive summary is followed by the report, with findings and recommendations for NSF, NASA and DOE regarding their support of the nation's astronomy and astrophysics research enterprise, along with detailed recommendations concerning specific projects and programs.

I would be glad to provide you with a personal briefing if you so desire.

Sincerely yours, on behalf of the Committee,

Martha P Haynes

Martha P. Haynes

Chair, Astronomy and Astrophysics Advisory Committee

cc: Senator John Thune, Ranking Member, Committee on Commerce, Science and Transportation, United States Senate

Senator Lisa Murkowski, Ranking Member, Committee on Energy & Natural Resources United States Senate

Representative Eddie Bernice Johnson, Ranking Member, Committee on Science, Space, and Technology, United States House of Representatives

Senator Bill Nelson, Chairman, Subcommittee on Science and Space, Committee on Commerce, Science and Transportation, United States Senate

Senator Ted Cruz, Ranking Member, Subcommittee on Science and Space, Committee on Commerce, Science and Transportation, United States Senate

Senator Barbara Mikulski, Chairwoman, Subcommittee on Commerce, Justice, Science, and Related Agencies, Committee on Appropriations, United States Senate

Senator Richard Shelby, Ranking Member, Subcommittee on Commerce, Justice, Science, and Related Agencies, Committee on Appropriations, United States Senate

Senator Dianne Feinstein, Chairwoman, Subcommittee on Energy and Water Development, Committee on Appropriations, United States Senate

Senator Lamar Alexander, Ranking Member, Subcommittee on Energy and Water Development, Committee on Appropriations, United States Senate

Senator Tom Harkin, Chairman, Committee on Health, Education, Labor and Pensions, United States Senate

Representative Larry Bucshon, Chairman, Subcommittee on Research, Committee on Science, Space and Technology, United States House of Representatives
Representative Daniel Lipinski, Ranking Member, Subcommittee on Research, Committee on Science, Space and Technology, United States House of Representatives
Representative Rodney Frelinghuysen, Chairman, Subcommittee on Energy and Water Development, Committee on Appropriations, United States House of Representatives
Representative Peter J. Visclosky, Ranking Member, Subcommittee on Energy and Water Development, Committee on Appropriations, United States House of Representatives
Representative Frank R. Wolf, Chairman, Subcommittee on Commerce, Justice, Science and Related Agencies, Committee on Appropriations, United States House of Representatives
Representative Chaka Fattah, Ranking Member, Subcommittee on Commerce, Justice, Science and Related Agencies, Committee on Appropriations, United States House of Representatives
Representative Steven Palazzo, Chairman, Subcommittee on Space and Aeronautics, Committee on Science, Space, and Technology, United States House of Representatives
Representative Donna Edwards, Ranking Member, Subcommittee on Space and Aeronautics, Committee on Science, Space, and Technology, United States House of Representatives
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Dr. Fleming Crim, Assistant Director, Directorate for Mathematical and Physical Sciences, National Science Foundation
Dr. John Grunsfeld, Associate Administrator, Science Mission Directorate, National Aeronautics and Space Administration
Mr. Chuck Gay, Deputy Associate Administrator, Science Mission Directorate, National Aeronautics and Space Administration
Dr. Paul Hertz, Director, Astrophysics Division, Science Mission Directorate, National Aeronautics and Space Administration
Dr. William Brinkman, Director, Office of Science, U.S. Department of Energy
Dr. Patricia Dehmer, Deputy Director for Science Programs, Office of Science, U.S. Department of Energy
Dr. James Siegrist, Director, Office of High Energy Physics, U.S. Department of Energy
Dr. Glen Crawford, Head, Research and Technology Division, Office of High Energy Physics, U.S. Department of Energy
Dr. Kathleen Turner, Program Manager, Office of High Energy Physics, U.S. Department of Energy
Dr. Tom Kalil, Deputy Director for Policy, Office of Science and Technology Policy, Executive Office of the President
Dr. Tamara Dickinson, Senior Policy Analyst, Office of Science and Technology Policy, Executive Office of the President
Dr. Gerald Blazey, Assistant Director, Physical Sciences, Office of Science and Technology Policy, Executive Office of the President
Dr. J.D. Kundu, Program Examiner, NASA and NSF, Office of Management and Budget
Dr. Arti Garg, Program Examiner, DOE, Office of Management and Budget
Dr. James Ulvestad, Director, Division of Astronomical Sciences, National Science Foundation
Dr. Patricia Knezek, Deputy Director, Division of Astronomical Sciences, National Science Foundation
Dr. Thomas Statler, Program Director, Division of Astronomical Sciences, National Science Foundation

Astronomy and Astrophysics Advisory Committee Members:

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- Dr. Stefi Baum, Rochester Institute of Technology
- Dr. James Buckley, Washington University St. Louis
- Dr. William Cochran, University of Texas at Austin
- Dr. Priscilla Cushman, University of Minnesota
- Dr. Debra Elmegreen, Vassar College
- Dr. Joshua Frieman, Fermilab, University of Chicago
- Dr. Martha Haynes, Cornell University (chair)
- Dr. Mordecai-Mark Mac Low, American Museum of Natural History
- Dr. Geoffrey Marcy, University of California, Berkeley
- Dr. Richard Matzner, University of Texas, Austin
- Dr. Paula Szkody, University of Washington
- Dr. Paul Vanden Bout, National Radio Astronomy Observatory

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Executive Summary

The Astronomy and Astrophysics Advisory Committee (AAAC) advises the Department of Energy (DOE), the National Aeronautics and Space Administration (NASA) and the National Science Foundation (NSF) on selected issues within the field of astronomy and astrophysics that are of mutual interest and concern. Established in the NSF Authorization Act of 2002, the AAAC is chartered to assess and make recommendations regarding the coordination of the agencies' astronomy programs, to assess the status and make recommendations regarding agency activities as they relate to the National Research Council (NRC) astronomy and astrophysics decadal surveys, and to report the committee's assessments and recommendations annually to the Secretary of Energy, the NASA Administrator, the NSF Director and the relevant committees in the House and Senate. This communication represents the annual report of the current committee and includes an examination of interagency coordination, particularly in the context of the 2010 NRC decadal survey report "New Worlds, New Horizons in Astronomy and Astrophysics" (NWNH) and its predecessors. Because of the current federal budget uncertainty, the AAAC this year is unable to comment in detail on a number of programs and issues before it. Hence, this report is more limited in budgetary detail than it might otherwise be.

Recommendations

A. Assessment of the Status of Interagency Coordination

Partnerships and collaborations involving agencies, nations, states, and private institutions are becoming more common, especially in the development and operation of expensive and complex facilities. The AAAC was asked for specific advice on what constitutes a successful interagency partnership, and concludes that programmatic partnerships among agencies or involving other entities are appropriate when they deliver increased science capability, cost effectiveness, access to specialized expertise and avoidance of duplication. The three agencies, DOE, NASA and the NSF, are currently cooperating in a large number of interagency programs which meet these criteria. Appendix B provides a list of interagency cooperative programs.

- <u>Recommendation</u>: **When funding major cooperative interagency programs, the Congress, the Office of Management and Budget (OMB) and the Office of Science and Technology Policy (OSTP) should ensure that funding is provided on a coordinated schedule consistent with the multiagency partnership.**

B. Assessment of the Status of Decadal Programs and Recommendations

The Atacama Large Millimeter/submillimeter Array (ALMA) represents the culmination of nearly 30 years' effort by the international astronomical community to develop and construct a transformational telescope to explore the dust and gas associated with the origins of stars, planets, galaxies and the universe itself. The James Webb Space Telescope (JWST) is on course for an October 2018 launch, with several key components now complete, in testing, or about to be delivered. The AAAC concludes that the NASA replan is providing an effective framework for success in building JWST. At the same time, however, current budget restrictions prevent implementation of many of the recommendations of NWNH. Broad, community-based reviews such as the recent NSF –AST Portfolio Review and the on-going high-energy physics community American Physical Society/Division of Particles and Field (APS/DPF) Snowmass process provide the agencies with valuable advice and perspective.

- **<u>Recommendation</u>: In circumstances of restricted budgets that diminish the ability to carry out decadal recommendations along with existing programs, the prioritization of programs that are implemented should continue to involve a peer review process that includes input from the community.**
- **<u>Recommendation</u>: Within the limitations in NASA funding until JWST is launched, NASA should continue the development of the Wide Field InfraRed Survey Telescope (WFIRST) mission as the highest priority large space mission in NWNH.**
- **<u>Recommendation</u>: The NSF and DOE should continue to develop the Large Synoptic Survey Telescope (LSST) as the highest priority large ground-based facility in NWNH.**
- **<u>Recommendation</u>: Within its long range program planning, NASA should continue to support the development of Explorer-class missions to enable rapid response to science opportunities as recommended as the second priority large space program in NWNH.**
- **<u>Recommendation</u>: Within its long range program planning, NSF should identify a path to support the Mid-scale Innovations program that was recommended as the second priority large ground-based program in NWNH.**

C. Assessment of the Integrated Astronomy and Astrophysics Enterprise

Science is an international enterprise funded by regions, nations, states, and private institutions and individuals. Many of the major scientific programs identified in NWNH will require combined analysis of data sets from disparate facilities, supported by simulations and theoretical analyses, all funded by different players.

- **<u>Recommendation</u>: The agencies should implement a flexible open skies policy that both affirms the ideal of open access and permits negotiation on access to federally-funded telescopes and data sets as required to establish a level of parity in access to foreign and non-federally-funded facilities and data sets.**

To achieve their full scientific potential, many of the major science programs of NWNH require coordinated and complementary efforts in multi-facility astronomical observations, simulations, theory and analysis.

- **<u>Recommendation</u>: Negotiations towards the coordination of projects or the development of partnerships should proceed on the basis of the principles of reciprocal participation and mutually agreed sharing of costs and responsibilities. Responsible agencies should coordinate early in project development to enable the maximum scientific return to the nation from the federal investment in facilities and core capabilities.**

To ensure our international competitiveness, investment in smaller and medium activities within the national infrastructure is critical for the training of students and early career scientists, the development of new technologies and software, and the advance of core capabilities in theory, computation and laboratory analysis. In addition, national open access to small and medium facilities is a vital component of this training and development. However, public access to facilities will be reduced due to divestments in the era of constrained astronomy budgets.

- **Recommendation: To produce the best and most innovative astronomy, achieve the decadal science priorities, and remain competitive on the international astronomy landscape, agencies should continue to strive for a balance among small and medium grants, projects and facilities, and programs across different disciplines.**
- **Recommendation: NSF should request a report led by the National Research Council (NRC) Committee on Astronomy and Astrophysics (CAA) to help define a revised national ground based optical/infrared (OIR) system, with a focus on the required instruments, telescopes, and public access to enable both the best science and broadest community participation in the LSST era.**

The landscape for U.S. astronomy and astrophysics is evolving and requires ongoing consideration of budgets, technical developments, and international efforts in order to enable the best science as recommended in NWNH.

- **Recommendation: The NRC Committee on Astronomy and Astrophysics (CAA) or a committee it forms should be charged with carrying out a mid-decade review of progress on NWNH survey goals and consideration of technical decision points on the program going forward. At the same time, agencies should rely on community input (including advisory committees such as this one, and peer review as mentioned elsewhere in this report) to make decisions on projects and facilities in the nearer term in order to position the U.S. astronomy enterprise for success in the coming years.**

The trial initiation of the Plutonium-238 (Pu-238) production pipeline to support power supplies for spacecraft missions to explore the outer Solar System is underway. Other mission critical consumables including Helium-3 (He-3) and Helium-4 (He-4), which enable a range of astronomy research as well as commercial and national security endeavors, remain in short supply.

- **Recommendation: Prompt action should be taken, through coordination between DOE, NASA, and, if applicable, other federal agencies, to support the Pu-238 project production scale-up, and to assure sufficient availability of He-3 and He-4.**

The AAAC is fully aware of the budget limitations and uncertainties that face all constituencies supported by the federal agencies. The astronomical community is accustomed to setting strategic priorities and will continue to do so. The AAAC remains very concerned about the long term impact of the current exigencies on the ability of the U.S. astronomical community to retain its leadership position in the worldwide research enterprise.

1. Introduction

This document constitutes the annual report of the Astronomy and Astrophysics Advisory Committee (AAAC) in response to its charter established in Section 23 of Public Law (PL) 107-368 (the National Science Foundation Authorization Act of 2002) and amended by Section 5 of PL 108-423 (the Department of Energy High-End Computing Revitalization Act of 2004). The AAAC charter directs the committee to perform three tasks: first, to assess and make recommendations regarding the coordination of astronomy and astrophysics programs at the DOE, NASA and the NSF; second, to assess and make recommendations regarding the status of the activities of the three agencies as they relate to the recommendations of the astronomy and astrophysics decadal surveys; and, third, to report annually (this document) on those assessments by March 15th of each year.

During the last year (since 15 March 2012), the AAAC met twice face-to-face and three times via teleconference. Representatives of the three agencies have given briefings and provided input on the status of their programs. A representative of OSTP attended the face-to-face meeting in February 2013. Because at the time of the writing of this report, the FY13 budget has not yet been passed by Congress and the FY14 President's budget request has not yet been released, we have been unable to review with the agencies their detailed plans for the current and upcoming year. This report then is less substantive in terms of budgetary assessment than it would be under different circumstances. Furthermore, in the interest of brevity, we have been selective in the issues we include in this report. Absence of discussion herein does not imply lack of interest on the part of the committee.

2. Assessment of the Status of Interagency Coordination and Cooperation

The AAAC is specifically tasked with reviewing programs in astronomy and astrophysics which involve the coordinated engagement of more than one of the three agencies, the DOE, NASA and the NSF. In the discussion here, we focus on programs which are undertaken not just in coordinated manner but as collaborative programs in which the partners including the agencies contribute identifiable assets.

Astronomical facilities, both in space and on the ground, are often expensive, technologically advanced and complex. Furthermore, the acquisition, processing and public distribution of huge astronomical data sets require the development of sophisticated algorithms and pipelines and large investments in computing power. As indicated in the selected scientific and technical highlights presented in Appendix A of this document, astronomical discoveries and increasingly sophisticated technological capabilities continue both to astound and amaze us. Matching ambition to practicality drives large collaborations to build and operate expensive new facilities, to engage in the analysis of the data sets they produce, and to expand the horizon of knowledge they enable through associated theoretical, computational and laboratory studies.

Finding: *Partnerships and collaborations involving federal and international agencies, nations, states, and private institutions are becoming more common, especially in the development and operation of expensive and complex facilities.*

Appendix B provides a list of cooperative programs involving at least two of the agencies DOE, NASA and NSF. Brief details of the contributions of individual agencies to those projects are indicated.

A. Criteria for Assessing the Value of Cooperative Programs

In response to a request for specific advice on the criteria by which the undertaking of a coordinated interagency program or partnership with other entities should be considered advantageous, the AAAC has formulated the following criteria for assessing the value of a cooperative program. Interagency cooperation is advantageous if the joint program

1. Enables additional, better or faster science productivity;
2. Offers the opportunity for increased cost effectiveness or cost saving in terms of the science return;
3. Taps unique expertise at each of the multiple agencies involved;
4. Avoids duplication of effort.

Conclusion: *Programmatic partnerships among agencies or involving other entities are appropriate when they deliver increased science capability, cost effectiveness, access to specialized expertise and avoidance of duplication.*

B. Examples of Interagency Cooperative Programs

Among the numerous programs listed in Appendix B, we have chosen three to serve as illustrative examples.

1. The NASA Long Duration Balloon Program (LDBP) operating at the NSF McMurdo Station in Antarctica. An important component of the NASA suborbital program is the deployment of unmanned balloons which carry scientific payloads into the space environment for extended periods of time. Antarctica is a particularly attractive site for long duration ballooning because the polar vortex insures little atmospheric or thermal change, allowing the balloon to stay at near-constant altitude over the Antarctic continent for long periods. For this program, NSF provides the communication and logistical infrastructure in support of NASA's science and technical program.

2. The Dark Energy Survey (DES) is using a powerful new camera, the DECam, funded by the DOE and fabricated by DOE's Fermilab, on the 4-meter diameter Blanco telescope at NSF's Cerro Tololo Interamerican Observatory (CTIO) to carry out high-precision measurements of 300 million galaxies in five optical filters and to observe smaller patches of the sky repeatedly every few days to discover and study thousands of distant supernovae. As suggested by its name, the DES is designed to probe the nature of dark energy and the mystery of cosmic acceleration. In this cooperative program, DOE is contributing both the camera and its core capability of large science collaborations while NSF supports the data management system and is operating the telescope and site. Furthermore, the DECam will be available to other users of the telescope for their own scientific research.
3. The committee notes, with pleasure, that NASA and the NSF have implemented a cooperative program, Theoretical and Computational Astrophysics Networks. Designed to enable research on the most complex theoretical challenges in astrophysics, this program was specifically recommended as a small program in NWNH and in the 2012 AAAC report.

Finding: *The three agencies, DOE, NASA and the NSF are currently cooperating in a large number of interagency programs that meet the evaluation criteria discussed in the previous section. Appendix B provides a list of interagency cooperative programs.*

The three agencies are not normally funded by the same pieces of legislation. Because of the manner in which agency budgets are appropriated, it is possible for such interagency program budgets to become "out-of-sync", with one agency's budget allowing the project to advance and the other, not.

<u>Recommendation</u>: When funding major cooperative interagency programs, the Congress, OMB and OSTP should ensure that funding is provided on a coordinated schedule consistent with the multiagency partnership.

3. Assessment of the Status of Decadal Programs and Recommendations

Since the 1960's, the astronomical community, under the auspices of the NRC, has undertaken a "decadal review" of the current state of the field and of the research priorities for the next decade, leading to a set of recommendations for a prioritized program for the subsequent decade. In practice, the design, development and construction of the largest astronomical facilities and missions take more than a decade to implement. In fact, several of the major facilities recommended by the 2000 decadal survey report "Astronomy and Astrophysics for the New Millennium" (AANM) are only now being completed or are still in progress. They make up key components of the scientific landscape envisaged by the subsequent 2010 decadal survey report

NWNH. Others included in the 2000 survey were never completed for a variety of reasons including budgetary constraints, technological challenges, or changing scientific priorities. Some projects considered by the 2000 committee were not viewed with the same priority by the 2010 review. The shift in prioritization reflects the astronomical community's own assessment of the most strategic investment of federal resources to achieve the highest priority science program. Difficult decisions are made by these decadal reviews, but by adopting their strategic vision, the astronomical community hopes to implement an optimal program under evolving scientific, technological and budgetary circumstances.

Here we summarize the status of major programs/facilities endorsed by the 1990, 2000 and 2010 astronomy and astrophysics decadal surveys which are currently in design, development or construction.

A. Implementation of Major Programs Recommended by Previous Decadal Surveys under Development or in Construction

Four major astronomical facilities recommended by previous surveys have achieved recent milestones.

ALMA: The Atacama Large Millimeter/submillimeter Array
Recommended by the 1990 decadal survey as the Millimeter Array, ALMA is the world's most sensitive and highest resolution telescope designed to provide exquisite imaging and spectroscopy in the millimeter and submillimeter wavelength ranges. It is an international partnership involving the United States, Canada, Japan, Taiwan and the European Southern Observatory on behalf of Europe. By combining their separate resources, the global astronomical community has achieved a facility with greatly enhanced capabilities. The last of the 25 North American ALMA antennas was delivered to Chile in November 2012 , and as of February 2013, all of them had been transported to the array site on the Chajnantor plateau at 16,500 feet. The inauguration of the full array is being held on March 13, 2013 just as we deliver this report. The inauguration marks the transition to operations of this major truly worldwide project. Early ALMA science with a partial array over the last year has already delivered spectacular discoveries.

Finding*: ALMA represents the culmination of nearly 30 years' effort by the international astronomical community to develop and construct a transformational telescope to explore the dust and gas associated with the origins of stars, planets, galaxies and the universe itself.*

SOFIA: Stratospheric Observatory for Infrared Astronomy
Endorsed by the 1990 decadal survey, SOFIA, a joint project of NASA and the German Aerospace Center (DLR), operates a 2.5 meter diameter telescope in a Boeing 747 aircraft that

can be flown at altitudes as high as 40,000 feet giving access to wavelengths from 0.3 microns (the visible) to 1.6 millimeters including a large portion of the far infrared spectrum not visible from the ground. Still in the commissioning phase, SOFIA will reach full operational capability with a complete suite of instruments in 2014. Early science results are providing new insights into dust and large molecules in and around forming stars and planets and near the supermassive black hole at the center of the Milky Way.

JWST: James Webb Space Telescope

The highest priority large space mission from the 2000 decadal survey report, JWST is on course for an October 2018 launch. NASA's replan, which included reorganized management of the project with direct reporting and several milestones to be accomplished each month, has resulted in a much more effective management structure. The JWST project has been steadily reducing technical risk on the JWST project and any remaining risk is proactively tracked. The AAAC commends NASA for its successful completion of several key phases. As of January 2013, over half of the manufacturing risk has been retired, and JWST is just over its halfway point in its development phase spending profile. All 18 mirrors are complete, and many other components are complete or undergoing testing. The Cryo-Vac test of the Integrated Science Instrument Module (ISIM), which houses the four science instruments and nine instrument support systems, will take place this year. The NIRCam imager has undergone their first Cryo-Vac testing, and should be delivered to Goddard Space Flight Center this spring for environmental testing. Issues with the NIRSpec spectroscope have been successfully resolved, and it will be Cryo-Vac tested in July 2013. MIRI and FGS will be delivered to Goddard this summer. The ground segment and operations efforts include contributions by Space Telescope Science Institute engineers and programmers to support operations products, archives, and data analysis.

Finding: *JWST is on course for an October 2018 launch, with several key components now complete, in testing, or about to be delivered*.

Conclusion: *The NASA replan is providing an effective framework for success in building JWST.*

ATST: Advanced Technology Solar Telescope

Endorsed by the 1990 decadal survey, the ATST will be the world's largest telescope dedicated to monitoring the Sun. Located at the Haleakalā High Altitude Observatory in Hawai'i, the ATST will make extremely high resolution images of the Sun using the technique of adaptive optics. Monitoring the Sun over days and months will allow solar physicists to detect solar flares and follow their evolution and to investigate the influence of magnetic fields. The detailed study and monitoring of the Sun is of critical importance to space weather forecasting. On-site construction of the ATST began in November 2012.

B. Implementation of the 2010 Decadal Survey "New Worlds, New Horizons in Astronomy and Astophysics"

NWNH produced recommendations for a coherent strategy for space and ground-based astronomy for 2012-2021 that included a balance of large, medium and small new initiatives along with ongoing support of a core research program. This plan was determined within budget scenarios that were realistic at the time: flat in 2010 dollars for NASA (with a 2014 launch of JWST) and flat or doubling budgets for NSF and DOE. The report stated that a flat budget would necessitate large reductions in facilities and research budget lines to accomplish the proposed goals. However, current budget trends appear to place astronomy funding at the flat level (in real year dollars) rather than at a doubling scenario for the foreseeable future and the launch delay of JWST to 2018 has driven increased costs for NASA. This budget environment means that many of the recommendations of NWNH cannot be accomplished. In order to set priorities within the current budget constraints, the astrophysics division of NASA formulated its Astrophysics Implementation Plan, and the NSF Division of Astronomical Sciences (NSF-AST) convened a Portfolio Review Committee (as recommended by NWNH pp. 32, 173). The high energy physics community under the auspices of the APS/DFP is engaging in a community review called the Snowmass process.

The NASA Implementation plan envisions no new start for a large mission until funding for JWST decreases in 2017. Until then, mission concepts for WFIRST as well as missions for a probe-class budget are being considered, several small-medium size missions will be accomplished under the Explorer Program and the core research and analysis programs have been augmented by 10% (from FY11 to FY12)

The NSF Portfolio Review Committee provided recommendations under two budget scenarios for the AST division in 2022: 65% and 50% of the NWNH projections. Its deliberations focused on trying to advance the NWNH science goals through a balanced program of large, medium and small initiatives within these very limited budget caps. Both scenarios would require divestment of some facilities and both would yield less access to telescope facilities for the national community. The 50% projection would not provide any public access to 20-30 meter diameter optical/infrared (OIR) or wide-area submillimeter telescopes, and funds for instrument upgrades would be reduced. Funding for individual investigator grants and midscale programs would also not meet expected levels in the balanced program recommended in NWNH; in fact, budget constraints have forced reductions of both the Astronomy and Astrophysics Research Grants (AAG) and Advanced Technologies and Instrumentation (ATI) programs in the last year.

Finding: *Current budget restrictions prevent implementation of many of the recommendations of NWNH.*

Finding: *Broad, community based reviews such as the recent NSF Portfolio Review and the on-going high energy community APS/DPF Snowmass process provide the agencies with valuable advice and perspective.*

Recommendation: **In circumstances of restricted budgets that diminish the ability to carry out decadal survey recommendations along with existing programs, the prioritization of programs that are implemented should continue to involve a peer-review process that includes input from the community.**

While budgetary constraints are greatly reducing the agencies' abilities to implement even the high priority recommendations of NWNH, we note briefly progress in the last year toward the implementation of the highest priority large programs identified in NWNH.

WFIRST: Wide Field Infrared Survey Telescope

The highest priority largest space mission recommended by NWNH, WFIRST is a wide field infrared space telescope intended to enable fundamental advances in the understanding of dark energy, in the discovery of exoplanets and in infrared survey science. NASA is exploring several concepts for implementation of the science capabilities of WFIRST as detailed in NWNH as a flagship and a probe-class mission. The agency is also exploring the use of 2.4 meter diameter telescope assets provided by the National Reconnaissance Office to advance the science of WFIRST.

Recommendation: Within the limitations in NASA funding until JWST is launched, NASA should continue the development of the WFIRST mission as the highest priority large space mission in NWNH.

LSST: Large Synoptic Survey Telescope

The highest priority largest ground-based facilities recommended by NWNH, the LSST is a multipurpose ground based telescope designed to explore the nature of dark energy and the behavior of dark matter along with a broad astronomical program. In addition, the synoptic nature of the LSST opens up our view of the time variable universe, discovering and monitoring objects that either move or change in brightness with time. The LSST is a joint project of the DOE, which will build its camera, the NSF, which will build the telescope and associated operational infrastructure and data management system, and private partners who have already contributed to site preparation and advanced technology development. The acquired data will be available to all U.S. scientists. The collaboration which will design and execute the LSST surveys and analyze its data sets includes scientists from both agencies' communities. During 2012, both agencies conducted successful in-depth reviews of their individual programs. At the NSF, the LSST is being considered for construction under the Major Research Equipment and Facilities Construction (MREFC) program. The FY2013 President's Request Budget includes the start of fabrication of the LSST camera by DOE.

Recommendation: The NSF and DOE should continue to develop the LSST as the highest priority ground based facility in NWNH.

NWNH recommended as second priority both in space and on the ground, not single facilities, but significant increased support for modest programs: an augmentation to the Explorer program for NASA and support for a Mid-scale Innovations program for NSF. Both of these recommendations reflect the importance to the astronomical community of establishing a capability to respond on shorter timescales to advances in science and technology and a need to retain balance both in terms of required investment and breadth across the field.

Augmentation to the Explorer Program

The NASA Explorer program supports small- and mid-sized Explorer missions that are developed and launched on a timescale of five years. Explorer-class missions therefore can respond to new discoveries and new technical capabilities, and over the last decades, such programs have provided critical insights into the universe and its constituents. In June 2012, the Nuclear Spectroscopic Telescope Array (NuSTAR) successfully achieved orbit; this small Explorer (SMEX) mission is intended to study collapsed stars and black holes in our own Milky Way Galaxy, the remnants of supernova explosions, and the supermassive black holes that power distant galaxies. Just recently, measurements made with NuSTAR have helped to measure for the first time the spin rate of a supermassive black hole; see Appendix A for a brief discussion.

Recommendation: Within its long range program planning, NASA should continue to support the development of Explorer-class missions to enable rapid response to science opportunities as recommended in NWNH.

Mid-Scale Innovations Program

As its second priority for ground-based projects, NWNH called out the importance of mid-scale experiments and projects with costs ranging between the limits of the NSF Major Research Instrumentation (MRI) and MREFC program. Highly successful and critical projects of this scope have been funded by NSF in the past. The NWNH recommendation encourages a more structured approach, including a competitive peer review process.

Recommendation: Within its long range program planning, NSF should identify a path to support the Mid-Scale Innovations program that was recommended in NWNH.

4. One Universe: The U.S. Role in the Integrated Astronomy and Astrophysics Enterprise

Science is an international enterprise funded by regions, nations, states, and private institutions and individuals. This situation is particularly true for astronomy, where major facilities such as telescopes have been funded by all of the above players, in combination and separately. The benefits of interagency coordination discussed in Section 2 apply on an even larger scale as the cost and complexity of facilities grow. Furthermore, many of the major scientific programs identified in NWNH will require combined analysis of data sets from disparate facilities, supported by simulations and theoretical analyses, all funded by different players. This raises the fundamental questions of: “Who pays?” and, “Who participates?”

The stakeholders in facilities constructed and operated by partnerships expect to receive scientific benefit commensurate with their investments. This “pay to play” approach to telescope access has long been standard procedure at U.S. privately owned facilities and at some major foreign facilities. It is, however, in direct contrast to the “free to all” policy (often referred to as ``Open Skies’’) that has been the tradition at the U.S. (NSF) national observatories and many, largely radio, foreign observatories. The conflict between these policies has given rise to a growing sense that there is inequity of access to telescope time and data products for the U.S. astronomical community.

A similar issue exists in the allocation of observing time on ALMA, where all time allocations to non-partner scientists, beyond a small amount of time shared by all partners, are charged to the U.S. A similar circumstance affects SOFIA. While 20% of the time is allocated as a Germany-only program, NASA uses its 80% share for an open call (exclusive of Germany). In an ideal world there would be open access to telescopes and data products. Reality drives increasing implementation of a pay-to-play approach.

<u>**Recommendation**</u>: **The agencies should implement a flexible open skies policy that both affirms the ideal of open access and permits negotiation on access to federally-funded facilities and data sets as required to establish a level of parity in access to foreign and non-federally-funded facilities and data sets.**

In astronomy, access to data has traditionally been restricted to the observer. More recently, many observatories, particularly space-based ones, have moved to making data available to the scientific community and the public after a proprietary period to give the original observer a chance to reap the benefits of their work by performing their analysis and publishing their results. Astronomy was one of the first fields to adopt widely the free distribution of preprints on the arXiv. In fact, the major U.S. astronomical research journals, under the auspices of the American Astronomical Society (AAS), provide open access one year after publication.

Moreover, the AAS makes its online journals available with no delay and at no charge to public libraries in the U.S.

Proposed observatories such as LSST move away from the concept of the individual observer entirely, instead surveying the entire southern sky at high cadence, and providing a resulting data set that will have applications for many astronomical fields of study. A specific concern arises from the strategic decision presented in NWNH to give first priority for construction to the LSST. Only after funding for its construction is secured will consideration be possible of significant NSF participation in the construction of a next generation OIR telescope such as the Giant Segmented Mirror Telescope (GSMT). This decision has been carefully considered by the NWNH committee as part of a deliberate strategy for the national astronomy program. However, on the global scale, it may result in an asymmetry of LSST follow-up capability that is unfavorable to the majority of U.S. astronomers. The imaging and time-domain surveys undertaken by the LSST will spark innumerable follow-up spectroscopic studies with the largest optical telescopes, including those to which much of the U.S. community has limited or no access. If the data products of the LSST are made equally available to the worldwide astronomical community, giving all astronomers regardless of affiliation the means to identify the prime targets for further investigation at no cost, the U.S. community's access to the large OIR telescopes required for these investigations will be limited to those with access to private telescopes. As another example, the European Space Agency (ESA) Euclid mission will require ground-based, multi-band optical imaging data in order to achieve its science goals; in the southern hemisphere, the two primary facilities that can provide such data will be at U.S. observatories, namely DES and LSST.

In an ideal world, making such data streams from U.S. facilities, and their statistically analyzed resulting products, freely available would maximize scientific productivity and discovery potential. However, in an era of constrained budgets, in which other, particularly international, players are maintaining proprietary data rights, realizing the value contained in such a data stream may be necessary in order to enable its existence and maintain U.S. competitiveness. In some cases, a requirement of contributions to operations costs in exchange for access to the data products, or some other form of exchange, may be a necessary mechanism to allow the program to move forward.

The federal agencies under our purview will need to work together and with project stakeholders to formulate coherent negotiating positions with our international partners, as different agencies are responsible for different segments of the program under negotiation. For example, NASA negotiates directly with ESA on the role of the U.S. in Euclid, but the LSST data set would be funded by NSF, DOE, and other partners. Although this committee is not tasked with providing a detailed plan of how to proceed, we can enunciate general principles that should be considered during such negotiations.

1. *Reciprocal participation.* The stakeholders responsible for the design and building of an instrument or observatory should have the chance to share in the exploitation of its results, including in combination with other data sets. This right should be limited to a proprietary period, however, with the data set produced by publicly funded facilities and its analyses ultimately being made freely available.
2. *Mutually agreed sharing of costs.* If analysis products from a facility are vital to the interpretation of the data from a second facility, some contribution to the building or operations of the first facility may be necessary in an era of constrained budgets. This contribution could be monetary or involve collaborative access to facilities or other data.
3. *Mutually agreed sharing of responsibilities.* All partners in such large-scale projects must be prepared to move forward with multilateral agreements in order to realize the scientific returns available.

Finding: *To achieve their full scientific potential, many of the major science programs of NWNH require coordinated and complementary efforts in multi-facility astronomical observations, simulations and theory.*

Recommendation: **Negotiations toward the coordination of projects or the development of partnerships should proceed on the basis of the principles of reciprocal participation and mutually agreed sharing of costs and responsibilities. Responsible federal agencies should coordinate early in the project development to enable the maximum scientific return to the nation from the federal investment in facilities, simulations, and analysis.**

5. Optimizing Scientific Innovation through Broad Participation

The best and most innovative science will result from broad community participation in astronomy. In order to facilitate this participation, core research must be sustained across fields, with a balanced program of support for small, medium, and large efforts, as discussed in NWNH. This message is reiterated in the NSF/AST 2012 Portfolio Review Committee report (p. 7), which encourages continued funding for a broad range of individual investigator grants and small and mid-scale programs and projects, in addition to enabling access to facilities and data, even in times of constrained budgets. Broad support under a balanced program will foster:

- **Innovation**: For example, suborbital missions, Explorers, and small telescopes provide test-beds for new technology.
- **Education**: For example, suborbital missions, Explorers, and small and medium ground-based telescopes (for radio, sub-mm, IR, optical or gamma-ray astronomy) provide hands-on training for students and early career astronomers and astrophysicists.

- **National infrastructure**: For example, individual investigator grants and small and mid-scale projects provide means to remain competitive on the international scene and to avoid ceding leadership of an entire field (e.g., X-ray, gamma ray, large optical telescope development) to another country by keeping America competitive in forefront research. Additionally, broad support helps the U.S. to maintain a diverse research infrastructure by providing support for a large number of small groups of highly trained engineers and technical staff located at numerous institutions.
- **Scientific productivity**: For example, even relatively modest-scale instruments provide fundamental capability for follow-up science in synergy with large missions/telescopes, particularly in studying moving or variable objects, in providing spectroscopy and simultaneous multi-wavelength coverage.

The success of the U.S. scientific enterprise requires the implementation of a balanced yet innovative program. In particular, as noted by numerous reports offered by numerous advisory committees, investment in small and medium programs should be maintained at an appropriate level within the overall strategic framework of the astronomy programs at the agencies. At the same time, because of budgetary constraints, difficult choices will be required. The consequences of those choices must be fully understood, not only in their short term implications, but also in their long-term effect on the strength and vitality of the U.S. astronomical community.

Conclusion: *To ensure our international competitiveness, open access to small and medium facilities for the training of early career astronomers and the development of new technologies and software must be maintained.*

Conclusion*: Investment in smaller and medium activities within the national infrastructure is critical for the training of students and early career scientists, the development of new technologies and software, and the complementary capabilities in theory, computation and laboratory analysis.*

<u>**Recommendation**</u>: **To produce the best and most innovative astronomy, achieve the decadal science priorities, and remain competitive on the international astronomy landscape, agencies should continue to strive for a balance among small and medium grants, projects and facilities, and programs across different disciplines.**

A serious and increasing concern related to the issues of access discussed in Section 4 arises with respect to access to adequate research facilities by the entire U.S. community regardless of institutional affiliation. According to the NSF-AST Portfolio Review committee report and the NWNH survey, half of U.S. astronomers have OIR telescope access only through open access. Yet in order to invest in NWNH priorities, difficult decisions must be made; in this case, the NSF Portfolio Review report recommends divestment from the Kitt Peak National Observatory (KPNO) facilities, directly resulting in the loss of ~700 nights of annual observing time to the national community. Similar divestment of radio telescopes operated by the National Radio Astronomy Observatory (NRAO) will likewise have a severe impact on the accessibility of the majority of its user community to the telescopes needed to conduct their research.

Finding: *Public access to facilities will be reduced in the era of constrained astronomy budgets.*

As an example of the impact on the community resulting from constrained budgets, consider the optical-infrared (OIR) ground-based community. The U.S. ground-based OIR system was intended to be an integrated suite of telescopes and instruments that would serve the general astronomical community through access to public and private facilities. The National Observatories were formed with the goal of providing competitively awarded observing time in the Northern and Southern hemispheres to all investigators. The construction and operation of increasingly expensive and large telescopes and instruments has been possible only through investment by private and state sources as well as, or in addition to, federal investment. Previous NSF programs such as the Telescope System Instrumentation Program (TSIP), the Renewing Small Telescopes for Astronomical Research (ReSTAR) program, and the Program for Research and Education with Small Telescopes (PREST) provided competitively awarded NSF funds to private observatories in exchange for limited public access to those telescopes or instruments. The situation is, however, becoming much more critical.

Some loss of open access to telescope time results from the designation of large blocks of telescope nights to key survey projects whose archival data products will benefit the broader community. In the OIR case, the impact of the potential loss of half the open access time will have severe effects on astronomers whose scientific programs cannot be addressed with archival data. Furthermore, open telescope access will maximize key follow-up science in support of discoveries with Hubble Space Telescope (HST), JWST, LSST and other large telescopes, for DOE experiments, NSF investigations, and NASA follow-ups, testing of new instrumentation on small telescopes, time-variable observations, and training of the next generation of astronomers. There is no overall roadmap for how to move forward in an era with severely restricted public access. The NSF portfolio review committee clearly identified the LSST as the cornerstone of the U.S. ground based OIR program at the end of this decade. With many small and medium size OIR telescopes within the community, a long term strategy addressing the scientific needs of the U.S. community for public telescope access and effective ways of leveraging such access would help to mitigate the loss of public access to OIR telescopes facing the U.S. community in the build-up to the LSST era.

Recommendation: NSF should request a report led by the NRC CAA to help define a revised national OIR system, with a focus on the required instruments, telescopes, and public access to enable both the best science and broadest community participation in the LSST era.

6. The Need for Continuing Community Input and Advice

The NWNH report called for an independent, mid-decade review of progress toward its goals, recognizing that the field of astronomy and astrophysics, the budget climate, and the international landscape would evolve and noting a number of technical decision points that would be reached after several years of progressive activity, discovery, and technical advances. NWNH referred to such a committee as the Decadal Survey Implementation Advisory committee (DSIAC). The NRC CAA has been reconstituted with support from NASA and NSF to fulfill the DSIAC role. The CAA is the natural venue to carry out or task a subcommittee to carry out such an independent review. While the AAAC is tasked in part with providing annual assessments of progress on decadal survey recommendations, it is not constituted to provide the independent strategic advice that a mid-decade review requires.

At the same time, while the mid-decade review will be important in providing mid-course advice on the evolving program, agencies will need to make decisions in the nearer term on projects and facilities based on decadal recommendations. These decisions can be informed through input from the community, including through advisory committees such as this one, and through merit review as mentioned elsewhere in this report, in order to maintain a strong U.S. astronomy enterprise in the coming years.

Conclusion: *The landscape for U.S. astronomy and astrophysics is evolving and requires ongoing consideration of budgets, technical developments, and international efforts in order to enable the best science as recommended in NWNH.*

Recommendation: The NRC CAA or a committee it forms should be charged with carrying out a mid-decade review of progress on NWNH survey goals and consideration of technical decision points on the program going forward. At the same time, agencies should rely on community input (including advisory committees such as this one, and peer review as mentioned elsewhere in this report) to make decisions on projects and facilities in the nearer term in order to position the U.S. astronomy enterprise for success in the coming years.

7. Selected Other Issues

This section briefly discusses two additional issues of particular importance to the AAAC this year.

A. Critical Supplies

The materials Plutonium-238 (Pu-238), Helium-4 (He-4) and Helium-3 (He-3) are individually essential to different aspects of space based astronomy and astrophysics. A manmade radioactive isotope, Pu-238 can be used to generate electricity via the heat emitted by its radioactive decay, either powering a heat engine or in a radioisotope thermoelectric generator (RTG). This vital element is necessary to power probes sent to the outer reaches of the solar system, a research area where the U.S. can clearly claim significant international leadership. He-4 is an essential material for very low temperature cooling of astrophysical experiments, providing cooling to one or two degrees above absolute zero, enabling otherwise impossible infrared observations. He-4 is also used in the NASA balloon program. A rare isotope that is naturally about one hundred thousand times less abundant than He-4, He-3 is a most important isotope in instrumentation for thermal neutron detection. He-3 is also used for cooling certain types of astrophysical detectors to temperatures that are only a few hundredths of a degree above absolute zero, temperatures that cannot be achieved with He-4 cooling systems. For reasons specific to each, these research critical isotopes have been expensive, and in some cases, very difficult to acquire at any price for astronomical research. This issue was also discussed by the committee in last year's report.

The AAAC was pleased to learn that the DOE has now successfully demonstrated a pipeline to produce Pu-238, by irradiation of Np-238 in a dedicated reactor followed by chemical purification. It will take about 8 years from initiation to full production of the required 5 kg/year, but scale-up to production is expected to occur on a timescale to support NASA flight plans with no interruption in supply.

Finding: *The trial initiation of the Pu-238 production pipeline to support power supplies for spacecraft missions to explore the outer Solar System is underway.*

Finding: *Other mission critical consumables including He-3 and He-4, which enable a range of astrophysics research as well as commercial and national security endeavors, remain in short supply.*

Recommendation: Prompt action should be taken, through coordination between DOE, NASA, and, if applicable, other federal agencies to support the Pu-238 project production scale-up, and to assure sufficient availability of He-3 and He-4.

B. Management of Polar Programs within NSF

During the past year, the NSF has streamlined its reporting structure by shifting the Office of Polar Programs (OPP) to the new Division of Polar Programs (POLAR) under the Directorate of Geosciences (NSF-GEO). The AAAC expects that coordination between NSF-GEO and NSF-AST will ensure that this organizational restructuring maintains the scientific excellence and vitality of the relevant astronomical programs operating under POLAR.

8. Conclusion

The AAAC is fully aware of the budget limitations and uncertainties that face all constituencies supported by the federal agencies. The astronomical community is accustomed to setting strategic priorities and will continue to do so. At the same time, however, the AAAC remains very concerned about the long term impact of the current exigencies on the ability of the U.S. astronomical community to retain its leadership position in the worldwide research enterprise.

In spite of the limitations, the last year has been an exciting one both in terms of the science and technical highlights such as those presented in Appendix A and in the progress towards the various programs mentioned here, especially those which directly result from the positive and proactive cooperation of the three federal agencies (Appendix B). The long term outlook raises serious concern, but we remain hopeful that the U.S. national astronomy and astrophysics program will continue to explore the vast reaches of the universe, discovering its secrets, and through them, inspiring future generations.

Appendix A: Selected Science and Technical Highlights of the Last Year

Many new discoveries and advances in astronomy and astrophysics have emerged in the last year. Here we present only a very brief sampling of research highlights supported by the federal agencies.

The Completion of ALMA:

Just as this report is being delivered, the international ALMA partnership is celebrating the inauguration of the facility, nearly 30 years after first planning for it began. Progress in the last year on both technical and research fronts has been tremendous. Of particular note to the construction phase, the last of the 25 antennas contributed by ALMA-North America was accepted. In addition, science results from the partial array are now appearing regularly and ALMA is fulfilling is scientific promise as a transformational instrument. The inauguration marks the transition to operations of this major truly worldwide project.

The last of the North American antennas is moved into position within the array. Photo courtesy of GD SATCOM Technologies – William Johnson

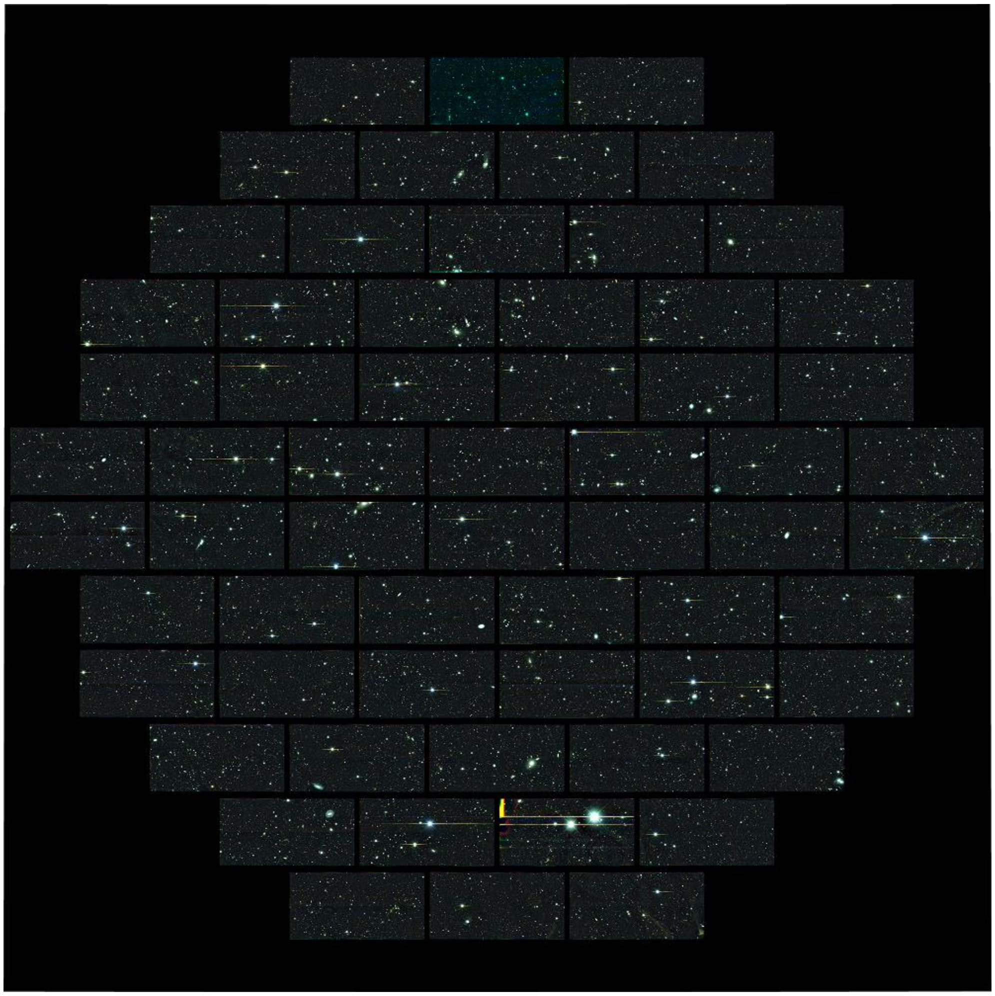
First Results from NuSTAR: X-ray Observations of the Spin of a Supermassive Black Hole

NASA's Nuclear Spectroscopic Telescope Array (NuSTAR), launched in June 2012, and ESA's XMM-Newton satellite have made the first definitive measurement of the spin of a supermassive black hole. The black hole is at the center of a nearby galaxy, NGC 1365, and its spin is causing the ejection of jets of material that illuminate the surrounding accretion disk of gas and dust, observed in X-rays. Einstein predicted that a fast-spinning black hole would have an accretion disk close to it whose X-ray light would be warped by gravity, as observed. NuSTAR and XMM-Newton provided conclusive observations of the spin rate by covering a range of X-ray energies that probed deep into the swirling disk. Black holes are of fundamental importance in understanding how galaxies form.

An artist's concept of a supermassive black hole surrounded by an accretion disk of dust and gas and an outflow of energetic particles powered by the black hole's spin. Credit: NASA/JPL-Caltech. (Research by Risaliti et al. 2013, Nature, 494, 449)

First Light for the Dark Energy Camera

On September 12, 2012, the 570-megapixel Dark Energy Camera saw first light on the National Optical Astronomy Observatory's Blanco 4-meter telescope at Cerro Tololo InterAmerican Observatory in Chile. Construction of the camera and its data management system by the Dark Energy Survey (DES) collaboration was jointly supported by the DOE, the NSF, and private and foreign partners. Over five years starting in 2013, DES will survey 300 million galaxies over one eighth of the sky and discover thousands of distant supernovae in the quest to probe dark energy and the origin of cosmic acceleration.



Composite image from the Dark Energy Camera on the Blanco 4-meter telescope at CTIO (from December 2012). The image shows the geometry of the 62 CCDs that cover its wide field of view. Credit: Dark Energy Survey.

The Interior State of Mercury

Mercury rotates three times for every two revolutions around the Sun; its spin axis is nearly perpendicular to its orbital plane. As Mercury orbit the Sun, it experiences periodically reversing torques due to the gravitational influence of the Sun on the asymmetric figure of the planet. The resulting oscillations, called forced librations, occur with a period of 88 days, the same as the orbit time. Green Bank and Goldstone radar observations of the spin state of Mercury indicate a longitudinal displacement of ~ 450 m at the equator. These measurements of the spin properties along with gravitational measurements using the MESSENGER spacecraft suggest that the mantle is decoupled from the molten inner core.

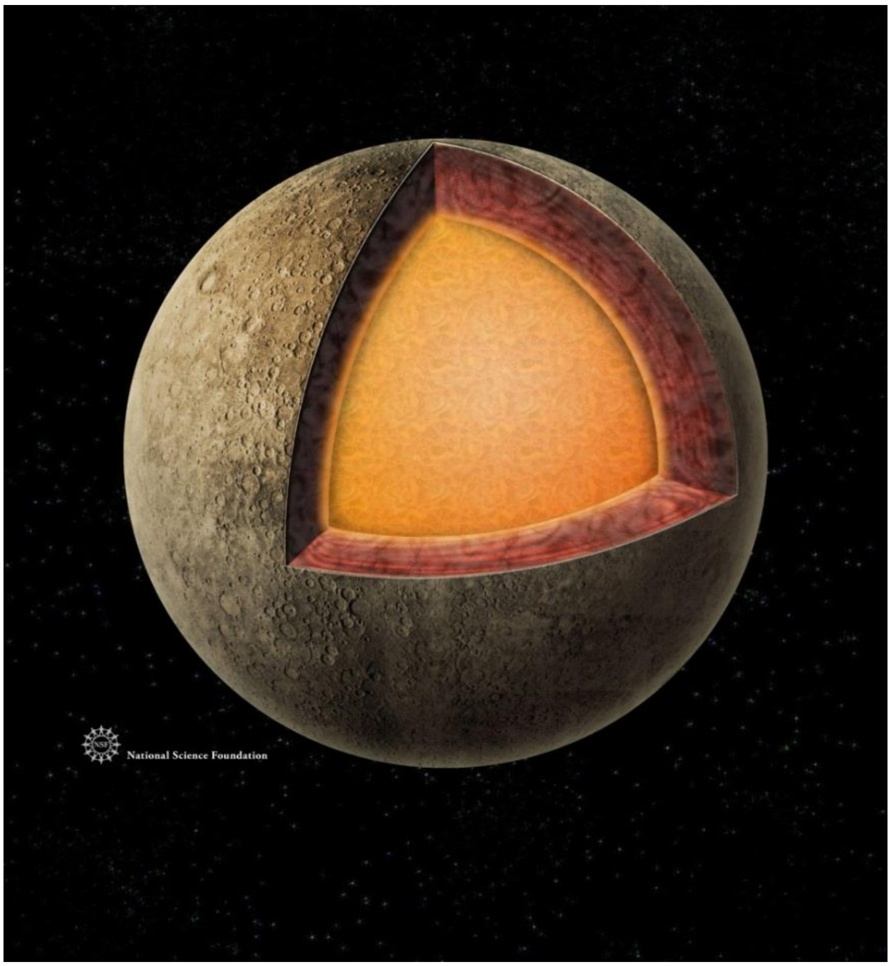
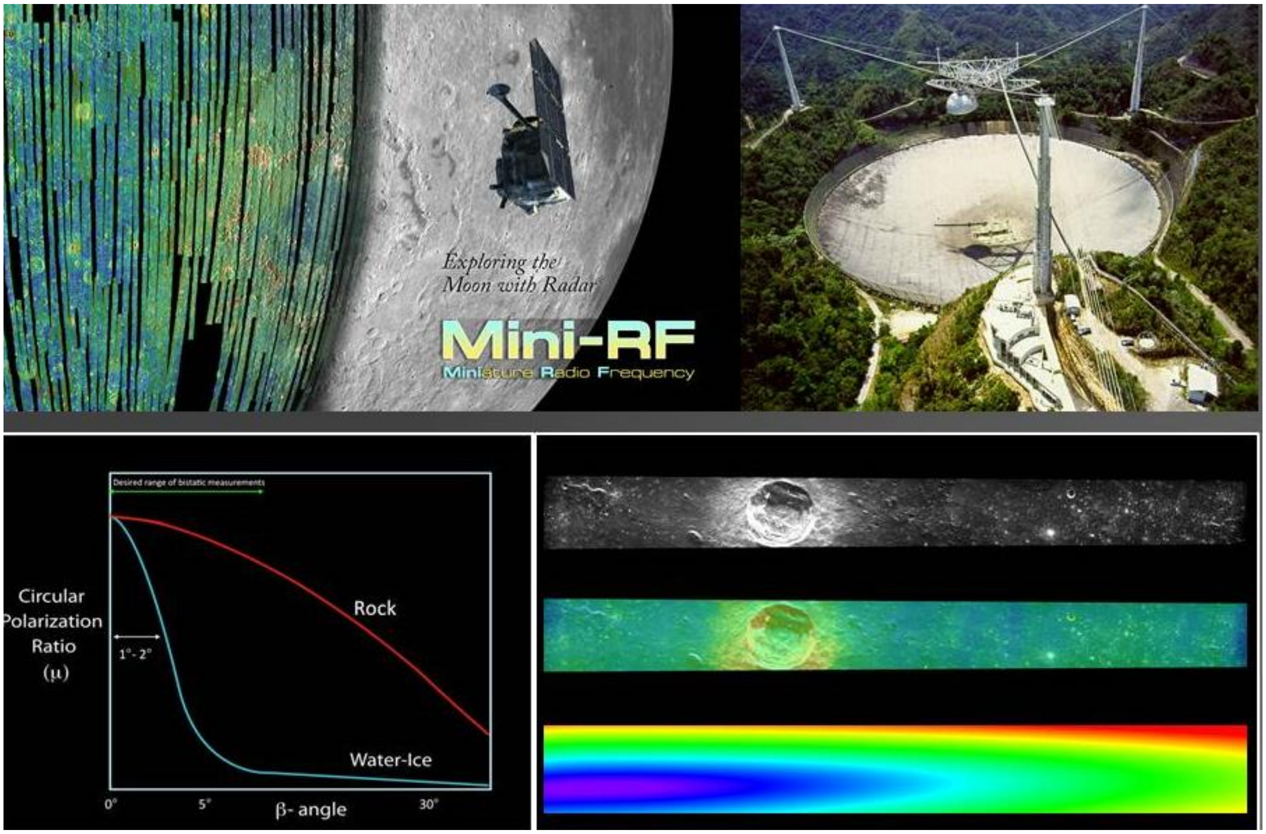


Diagram showing the interior structure of Mercury. The metallic core extends from the center to a large fraction of the planetary radius. Radar observations show that the core or outer core is molten. Image credit: Nicolle Rager Fuller, National Science Foundation. (Research by J.-L. Margot et al. 2012), J. Geophys. Res., 117, E00L09, doi:10.1029/2012JE004161 and Smith et al., Science, 336, 214–217 2012)

Evidence of Water on the Moon and Mercury



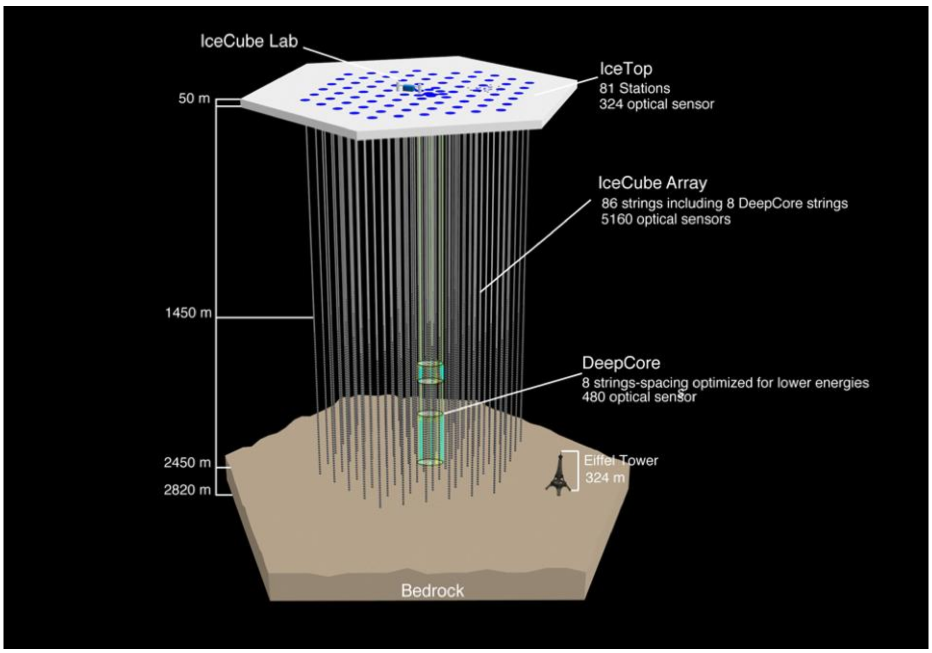
The Mini-RF project aboard the Lunar Reconnaissance Orbiter (upper left) receives the radar signal transmitted from the Arecibo radiotelescope (upper right) after it has bounced off the surface of the Moon. By taking advantage of our understanding of how a radio signal is reflected off a rocky surface versus an icy one (lower left), maps of the ice in the polar craters (lower right) can be constructed. Credit: NASA/JHU/APL.

The Mini-RF project aboard the Lunar Reconnaissance Orbiter (upper left) is currently mapping the north and south polar regions of the Moon, searching for deposits of ice within the top few meters of permanently shadowed craters. The radar signal, transmitted from Arecibo, reflects on the Moon's surface and is received by the orbiting Mini-RF instrument. The signal reflected off a rocky surface is very different from that reflected off water ice. Ice is clearly present at the lunar poles, deep in craters shielded from the sunlight. In 2012, the MESSENGER spacecraft used its own radar transmitter to confirm the presence of water ice in similar permanently-shadowed craters in the polar regions of the planet Mercury.

Missing Neutrinos in the IceCube GRB Neutrino Search

The IceCube Neutrino Observatory is an NSF-sponsored high energy neutrino telescope buried deep in the ice near the South Pole. Neutrinos are produced in high energy cosmic and solar events. When one of these neutrinos collides with a nucleus in the ice near the observatory, IceCube detects the faint blue light emitted by a secondary particle called a muon. Neutrinos easily travel through the entire Earth, rarely interacting with ordinary matter. IceCube is built on an enormous scale (one cubic kilometer of clear glacial ice) to compensate for their weak interactions and to catch some of their rare collisions. IceCube construction was finished in January 2011 by an international collaboration of 250 physicists and engineers.

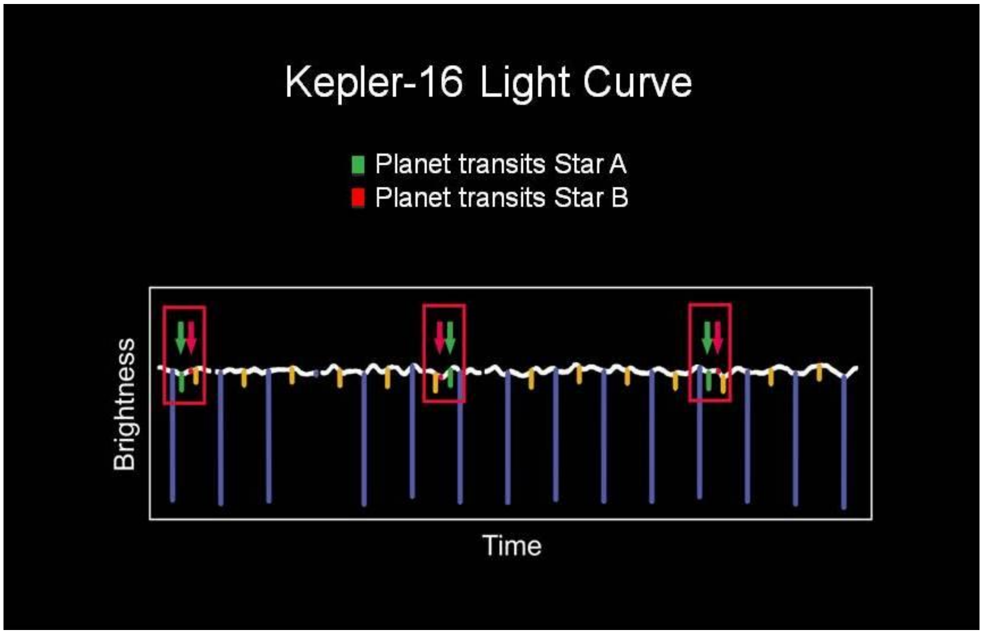
Gamma Ray Bursts (GRBs) are extremely powerful explosions. GRBs are relatively frequent occurrences, seen about once per day around the visible Universe. Typical GRBs last a few seconds, and during this brief time they can outshine the rest of the Universe combined. Despite this, little is known about them. The IceCube Collaboration studied 300 GRBs reported by GRB satellites between May 2008 and April 2010, looking for any neutrinos originating from the bursts. At the time, IceCube was operational but still under construction. It found no evidence for neutrinos associated with the GRBs at a 90% confidence limit, in a strong conflict with the theoretical prediction. GRB neutrino searches will continue with the now fully complete IceCube.



The IceCube Neutrino Telescope is made up of 86 strings with a total of 5,160 Digital Optical Modules that are used to sense and record neutrino events. Image credit: Danielle Vevea/NSF & Jamie Yang/NSF (Research by Abbasi et al. 2012, Nature, 484, 35; DOI:10. 1038/nature11068; http://arxiv.org/pdf/1204.4219.pdf)

Kepler Spacecraft Discovers a New Class of Circumbinary Planets

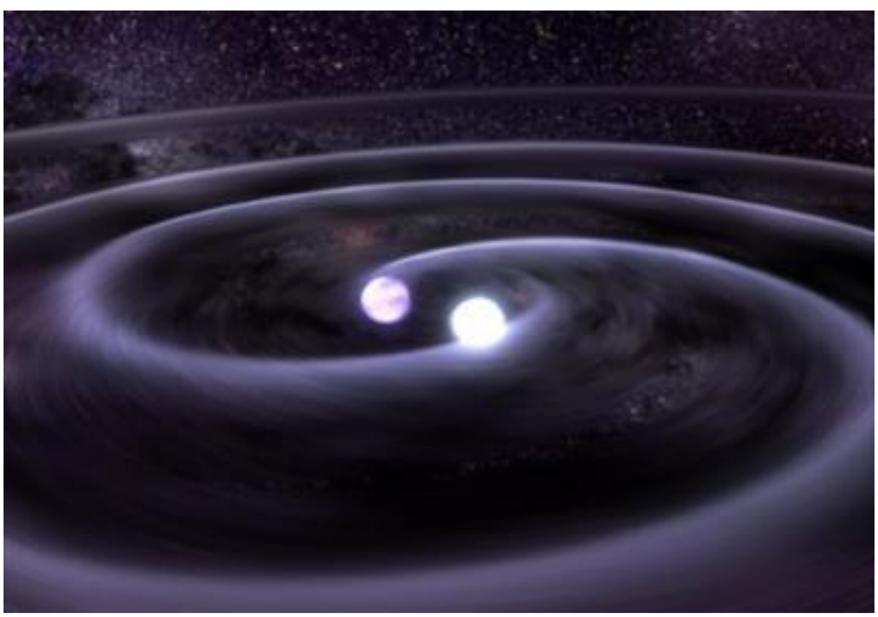
The NASA *Kepler* mission has discovered several examples of a previously unknown type of planet, dubbed a “circumbinary,” in which the planet orbits both stars of a binary star system. Such planets are discovered when they are observed to transit in front of both stars of an eclipsing binary star system. The two stars regularly pass in front of each other, causing dips in the light we detect. Additional dips in the total light occur when the planet passes in front of each star. Monitoring changes in the light allows the precise measurement of the planet’s size, density and mass. The fact that the orbits of the stars and the planet align to within a degree of each other indicate that the planet formed within the same circumbinary disk within which the stars formed, rather than being captured later by the two stars. While these Tatooine-like planets have been predicted to exist by both scientists and science-fiction writers, *Kepler* has provided the first definitive evidence of their existence. The *Kepler* spacecraft has now found a total of seven circumbinary planets, including one system with two planets orbiting the two stars.



The lightcurve of Kepler-16, showing the primary and secondary eclipses of the binary star (in blue and yellow) as well as the transits of the circumbinary star across the primary star (green) and across the secondary star (red). Credit: NASA.

Testing Einstein in a New Regime Using Pair of White Dwarf Stars

A team of astronomers has confirmed the emission of gravitational waves from the second-strongest known source in our galaxy by studying the shrinking orbital period of a unique pair of burnt-out white dwarf stars. Their observations tested Einstein's theory of general relativity in a new regime. The stars are so close together that they make a complete orbit in less than 13 minutes, and they should be gradually slipping closer. The system (called SDSS J065133.338+284423.37 or J0651 for short) is two remnant cores of stars like our Sun. Einstein's theory of general relativity predicts that moving objects create subtle ripples in the fabric of space-time, called gravitational waves. Though not yet directly observed, gravitational waves should carry away energy, causing the stars to inch closer together and orbit each other faster and faster. The team tested that prediction using more than 200 hours of observations from the 2.1-meter Otto Struve Telescope at McDonald Observatory in West Texas, the Frederick C. Gillett Gemini North telescope in Hawai'i, the 10.4-meter Gran Telescopio Canarias in the Canary Islands of Spain, and the 3.5-meter Apache Point telescope in New Mexico. Compared to the discovery of the binary in April 2011, the eclipses are now six seconds sooner. This confirms that the stars are getting closer and that the orbital period is shrinking by nearly 0.25 milliseconds each year, in agreement with expectations from general relativity. By April 2013, the eclipses should happen roughly 20 seconds sooner than they did relative to the first observations in April 2011.



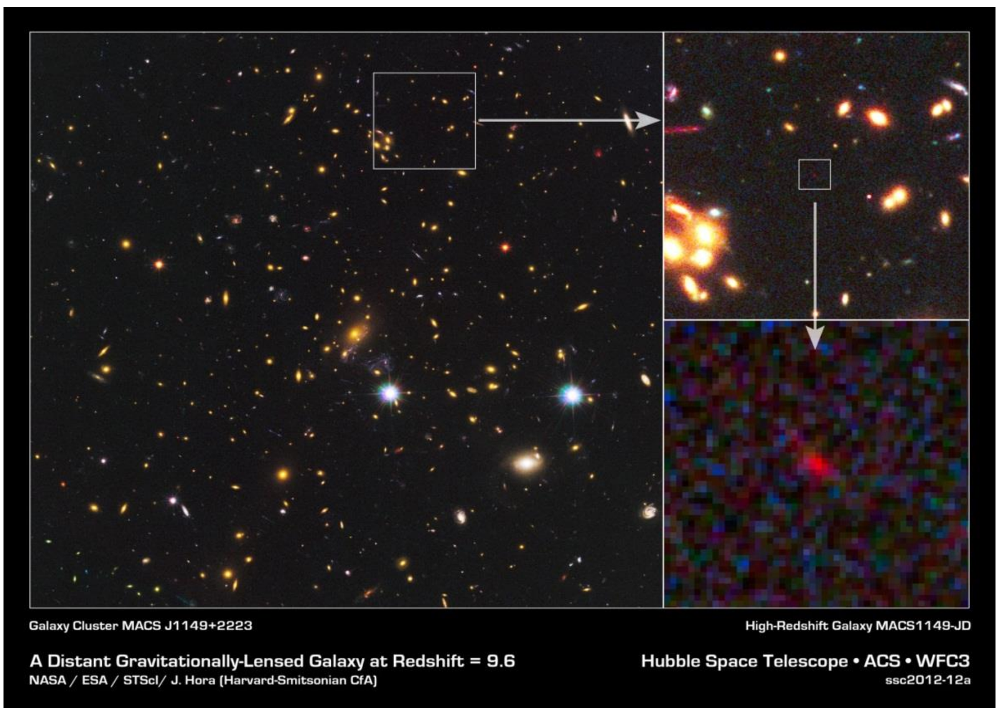
Artist's impression of the inspiral of a pair of white dwarfs. Credit: Berry/NASA GSFC. Research by Hermes et al 2012, Ap.J. 757, L31.

Discovery of a Galaxy at z ~ 10

With the combined power of NASA's Spitzer and Hubble space telescopes and a cosmic magnification effect, astronomers have spotted what could be the most distant galaxy ever seen. Light from the young galaxy first shone when our 13.7-billion-year-old universe was just 500 million years old, just 3.6 percent of its present age. Its observation opens a window into the important era when the universe began its transition from the so-called cosmic dark ages of a starless expanse to a recognizable cosmos full of galaxies (the epoch of *reionization*).

To observe this early, distant faint galaxy requires *gravitational lensing*, in which the gravity of foreground objects warps and magnifies the light from background objects. A massive galaxy cluster situated between our galaxy and the more distant galaxy magnified the distant galaxy's light, brightening the remote object some 15 times and making it detectable.

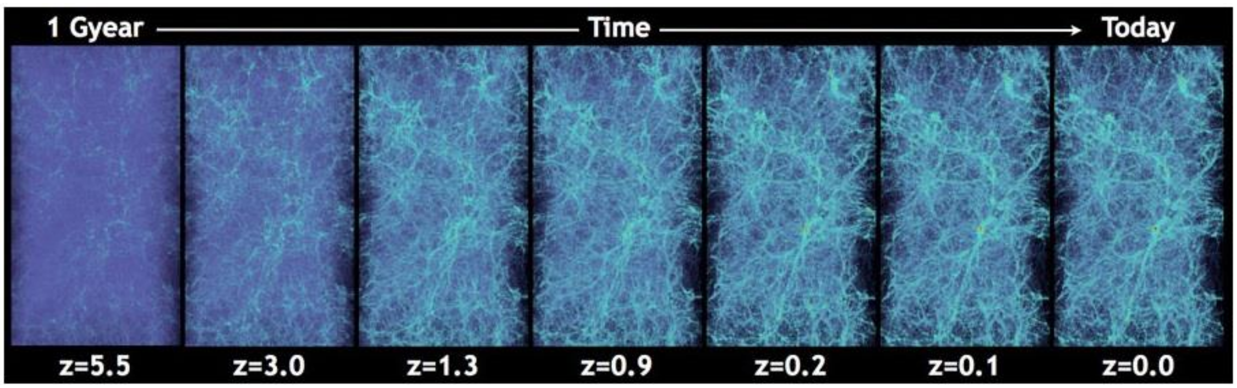
The galaxy was less than 200 million years old when it emitted the light we observe. It also was small and compact, containing only about one percent of the mass of our Milky Way galaxy, as expected from leading cosmological theories. Such tiny galaxies merge over time, eventually accumulating into the sizable galaxies of the more modern universe.



In the image at left, the many galaxies of a massive cluster called MACS J1149+2223 dominate the scene. Gravitational lensing by the giant cluster brightened the light from the newfound galaxy, known as MACS 1149-JD. At upper right, a partial zoom-in shows MACS 1149-JD in more detail, and a deeper zoom appears to the lower right. Image credit: NASA/ESA/STScI/JHU. (From Zheng et al., 2012, Nature, 489, 406

Computational Cosmology

Modeling the structure, evolution, and acceleration of the universe requires massive computation. A team led by Salman Habib and Katrin Heitmann of Argonne National Laboratory was a finalist for the 2012 Gordon Bell Prize of the Association for Computing Machinery for high performance computing for producing the largest and most detailed simulations of the universe to date, using DOE computers. The simulations provide an important framework for comparison with theories and observations of the universe’s development.



This sequence visualizes a computer simulation of the universe’s evolution, showing the development of large-scale structures, like clumps and filaments, from a billion years ago to today. The greater the redshift (“z”) of light from an object like a galaxy, the farther it is from the observer and thus the farther back in time we see it when its light reaches us today. Zero redshift means we are essentially seeing the object in real time – as it is today. *Image courtesy of Katrin Heitmann and Joe Insley, Argonne National Laboratory.*

Dark Matter in a Nearby Dwarf Galaxy from VERITAS

The VERITAS Array at the Fred Lawrence Whipple Observatory near Tucson, Arizona. Image credit: http://www.veritas.sao.arizona.edu

The Milky Way has a number of small satellite galaxies which, while barely visible in starlight, are host to large concentrations of dark matter. One of the closest of these dwarf satellites is Segue 1 which is thought to contain about 1000 times more dark matter than stars and gas. Very deep gamma ray observations of Segue 1 with the Very Energetic Radiation Imaging Telescope Array System (VERITAS) have recently placed some of the tightest constraints to date on hypothetical dark matter candidates known as weakly interacting massive particles (WIMPs). (Research by E. Aliu et al. 2012, Phys. Rev. D, 85, 062001.)

Appendix B: Active Interagency Cooperative Programs in Astronomy and Astrophysics

Acronym/Name	Program	Agency contribution
AMS	Alpha Magnetic Spectrometer (aboard the International Space Station)	DOE supports science mission (other countries contribute); NASA operates space infrastructure
Arecibo	Arecibo S-band Solar System radar	NASA supports radar program and telescope operations; NSF supports telescope operations
Auger	Pierre Auger Observatory	DOE supports the project office; DOE and NSF both contribute to the common fund (20 countries contribute).
BOSS	Baryon Oscillation Spectroscopic Survey (part of the Sloan Digital Sky Survey III)	NSF supports SDSS-III including BOSS; DOE-funded group leads BOSS and DOE provides partial support towards BOSS operations.
CTA	Cherenkov Telescope Array	NSF/PHY funds an MRI award.
DES	Dark Energy Survey	DOE provided camera and provides support towards camera operations; NSF provides operations of telescope, camera and observatory and data management; NSF provides the data management system.
	Dark matter detection experiments (COUPP, miniCLEAN, SuperCDMS, ADMX, DarkSide, Xenon, DAMIC, LUX)	DOE/NSF-PHY provide joint support (some joint; some not)
Euclid	Euclid: European Space Agency space observatory mission	NASA provides detectors; NASA/DOE provide support for science team; ESA is developing the space mission
Fermi	Fermi Gamma-ray Space Telescope	NASA runs the mission; DOE provides support for the Large Area Telescope Instrument Science Operations Center (ISOC)
HAWC	High-Altitude Water Cherenkov Observatory	DOE/NSF-PHY provide support for fabrication and operations
IRTF	Infrared Telescope Facility	NASA operates observatory; NSF provides funding for instruments and visitor support
Keck	Keck Observatory	NASA provides partial support for operations; NSF funds instrumentation for general users. Observing time allocated to agencies is made available to their respective user communities.

LDBP	McMurdo Long Duration Balloon programs (e.g Super Tiger, BLAST, EBEX)	NSF provides infrastructure; NASA supports balloon program
LSST	Large Synoptic Survey Telescope	DOE provides camera; NSF would provide telescope and site. Both would contribute towards telescope operations and science analysis
MS-DESI	Mid-scale Dark Energy Spectroscopic Instrument	DOE would provide spectrograph instrumentation ; DOE would provide support towards operations on a telescope and science analysis. NSF would provide telescope and site for eventual survey
PanSTARRS	Panoramic Survey Telescope and Rapid Response System	NASA funds NEO studies and serving of data through STScI; NSF is funding completion of PanSTARRS1 3-yr survey
Planck	Planck satellite mission	ESA operates satellite mission; NASA contributes to instruments and science team; DOE provides computational resources
SPT	South Pole Telescope	NSF provides telescope and site; DOE supplied provided outer ring of detectors for SPTpol phase
	Supernova programs (e.g. SNe Cosmology Project, Nearby SNe Factory, Palomar Transient Factory, QUEST)	DOE/NSF provide operations/science support for various projects
TCAN	Theoretical and Computational Astrophysics Network	NASA/NSF provide joint support
VAO	Virtual Astronomical Observatory	NASA/NSF provide joint support
VERITAS	Very Energetic Radiation Imaging Telescope Array System	DOE/NSF and Smithsonian provide joint support for operations and science analysis

Entries highlighted in yellow identify projects under development but not yet approved.

Appendix C: List of Acronyms

AAAC	Astronomy and Astrophysics Advisory Committee
AAG	Astronomy and Astrophysics Research Grants
AANM	Astronomy and Astrophysics for the New Millennium
ALMA	Atacama Large Millimeter/submillimeter Array
AMS	Alpha Magnetic Spectrometer
AST	Division of Astronomical Sciences
ATI	Advanced Technologies and Instrumentation
ATST	Advanced Technology Solar Telescope
BOSS	Baryon Oscillation Spectroscopic Survey
CAA	Committee on Astronomy and Astrophysics
CTA	Cherenkov Telescope Array
CTIO	Cerro Tololo Interamerican Observatory
DECam	Dark Energy Camera
DES	Dark Energy Survey
DSIAC	Decadal Survey Implementation Advisory Committee
DOE	Department of Energy
ESA	European Space Agency
FGS	Fine Guidance Sensor
GEO	Directorate for Geosciences
GRB	Gamma Ray Burst
GSMT	Giant Segmented Mirror Telescope
HAWC	High Altitude Water Cherenkov Observatory
He-3	Helium-3
He-4	Helium-4
HEP	High Energy Physics
HST	Hubble Space Telescope
IR	InfraRed
IRTF	Infrared Telescope Facility
ISIM	Integrated Science Instrument Module
JWST	James Webb Space Telescope
Keck	Keck Observatory
KPNO	Kitt Peak National Observatory
LSST	Large Synoptic Survey Telescope
LDBP	Long Duration Balloon Program
MIRI	Mid-InfraRed Instrument
MREFC	Major Research Equipment and Facilities Construction
MRI	Major Research Instrumentation
MS-DESI	Mid-Scale Dark Energy Spectroscopic Instrument

NASA	National Aeronautics and Space Administration
Np-238	Neptunium-238
NRAO	National Radio Astronomy Observatory
NRC	National Research Council
NSF	National Science Foundation
NuSTAR	Nuclear Spectroscopic Telescope ARray
NWNH	New Worlds, New Horizons in Astronomy and Astrophysics
OIR	Optical/InfraRed
OMB	Office of Management and Budget
OPP	Office of Polar Programs
OSTP	Office of Science and Technology Policy
PanSTARRS	Panoramic Survey Telescope and Rapid Response System
PL	Public Law
POLAR	Polar Programs
PREST	Program for Research and Education with Small Telescopes
Pu-238	Plutonium-238
ReSTAR	REnewing Small Telescopes for Astronomical Research
RTG	Radioisotope Thermoelectric Generator
SDSS	Sloan Digital Sky Survey
SMEX	SMall EXplorer Mission
SOFIA	Stratospheric Observatory for Infrared Astronomy
SPT	South Pole Telescope
TCAN	Theoretical and Computational Astrophysics Network
TSIP	Telescope System Instrumentation Program
VAO	Virtual Astronomical Observatory
VERITAS	Very Energetic Radiation Imaging Telescope Array System
WFIRST	Wide-Field InfraRed Survey Telescope